Although much of the buzz in the industry surrounds newer high-tech packages such as ball grid array (BGA), chip scale packages (CSP) and flip chips, the foundation of modern electronics is the lead frame package. The major lead frame package’s small outline ICs (SOICs) and plastic quad flat packs (PQFPs) make up the bulk of all surface mount IC packages manufactured in the world (Figure 1). With 70 billion produced in 2004, they represent about 70 percent of all surface mount packages. Every man, woman and child on Earth could be given 11 of these packages yearly.

The basic construction of a lead frame PQFP package is shown in Figure 2. The die is first bonded to the lead frame with an adhesive or soldering process. Wire bonding is used to form electrical connections from the active die pads to the package leads. A mechanical trimming operation separates the leads from the die bonding platform on the lead frame. Plastic is then injection-molded around the die and lead frame to form the typical black plastic body. The leads are formed in a “gull wing” or other standard shape. This process has been perfected over the years to the point that the costs have been driven quite low.

Die Attach: The Process

The die attach process involves affixing silicon die or chips to a lead frame or other substrate with adhesive, conductive adhesive or solder in the form of paste, solder wire or solder preforms. The bond normally is between the backside metallization of the die and the metal surface of the lead frame. The initial phase may involve attachment of a conductive metal clip between the top surface of the chip and the lead frame. In the case of power devices or in a subsequent step, wire bonding is performed between the lead frame and the topside of the chip. The final assembly is encapsulated in a mold compound for protection from moisture and the elements.

Lead Frames

A lead frame, the site of the die attachment, can vary in size, material of construction, complexity and cost. Essentially a perforated metal strip or plate, its construction is designed such that once the die mounting is finished the device can be cut out and portions of the lead frame serve as leads for the final encapsulated product.

Mounting various inexpensive devices takes place on a 0.5- to 3-in.-wide continuous lead frame strip made of copper or a simple copper alloy such as copper-beryllium (Figure 3). In some instances, the copper is plated with Sn/Pb alloys, pure tin or silver. In such a case, the lead frame typically will be propagated longitudinally from a reel through a robot that places molten solder or solder paste deposits, drops

Figure 1. World consumption of ICs by type. Note that small outline (SO) and plastic quad flat packs (PQFP) comprise roughly 70 percent of all ICs produced in the world.

the silicon die on the solder, reflo ws the pasted assemblies, and directs the strip through a cleaning operation before chopping the final product into lengths manageable in further processing.

In the case of mounting more expensive or elaborate chips, lead frames will be constructed by perfo-
rating metal plates in the range of 1.5 to 3 in. wide. These plates are 6 to 10 in. long and a few mils to macro thicknesses. Materials of construction include copper or copper alloys, but quite often a copper core is plated with nickel, covered with flash gold, palladium, or both. Or more recently, covered with silver. The surface platings serve to protect against corrosion and are more solderable than nickel, which is subject to severe dewetting in the case of varying phosphorous content. This type of lead frame has anywhere from a few to 100 or more mounting sites and is propagated through the construction robot on a wire belt by indexing in a lateral configuration.

### Backside Metallization

Ordinarily, the backside of the die must be coated with metal — most often several layers of different metals to allow soldering to the lead frame. The surface must be etched with HF and rinsed with water to remove SiO₂, which inhibits adhesion of gold, palladium, or both. Or more recently, covered with silver. The surface platings serve to protect against corrosion and are more solderable than nickel, which is subject to severe dewetting in the case of varying phosphorous content. This type of lead frame has anywhere from a few to 100 or more mounting sites and is propagated through the construction robot on a wire belt by indexing in a lateral configuration.

After this treatment, the surface is sputtered with 1,000 to 3,000 Å of titanium, which is volatile. The titanium forms a good diffusion barrier, and chemically consumes any remnant of SiO₂ on the surface. Nickel also can be applied by sputtering, but this sometimes induces unacceptable stresses. Electroless nickel processes appear to be more successful and are sometimes used in specialty cases.

Often, 2,000 to 4,000 Å of nickel or copper are added on top of the titanium, followed by 3,000- to 5,000-Å-layer of flash gold for protection and to improve solderability. It has become common to add a layer of silver for this purpose. Many variations are used, but most start with titanium, include a layer of copper or nickel, and then finish with protective layers of readily solderable flash gold, palladium or silver.

### Soldering

Soldering is a favored method for die attach to a lead frame, especially for power devices or rapid run mounting of inexpensive devices. The thermal conductivity of a metal solder is useful in dissipating the heat generated by power devices.

The source of the solder usually is in the form of a solder preform, solder wire or a solder paste. Development of methods involving screen printing deposits of molten solder, however, are underway.

### Alloys

The alloys used in die attach usually are in the 300°C liquidus range to allow mounting of the devices constructed on SMT boards with eutectic or Sn/Ag/Cu lead-free solder at temperatures of 200° to 250°C. Table 1 lists some commonly used alloys.

The first three alloys listed in Table 1 appear to be the most widely used in die attach. Sn5Pb85Sb10 is used for the second of two steps in soldering operations, where one of the first three alloys is used in a first step. By controlling the reflow profile, the first solder joint is not disrupted.

No completely satisfactory nontoxic lead-free alloy is available at this time to fill the roles of the first three alloys listed in Table 1. Au80Sn20 would be useful, but is prohibitively expensive. Others, such as Sn95Sb5, are just slightly too low in liquidus temperature. In any case, high-Sn alloys tend to be brittle, exhibit poor thermal cycling behavior and are susceptible to the Kirkendall effect in devices operating at elevated temperature. Bismuth is available and inexpensive but is the least metallic of all the metals. It offers relatively poor ductility and thermal and electrical conductivity. It is questionable whether Bi/Ag alloys will find wide application, despite having a suitable liquidus temperature.

### Solder Materials

Solder paste is a two-part mixture of spherical metal solder particles uniformly distributed in a liquid or semi-liquid vehicle. Each metal particle has the correct metal composition of the alloy, for example 5 percent tin and 95 percent lead for Sn5Pb95. One function of the vehicle is to carry a flux or fluxes that remove oxide from the solder particles and the substrates during reflow. However, the flux is a small portion of the vehicle that contains polymers, solvents, thixotropic agents to control rheology, anti-foams, surfactants and other additives. A major function of the vehicle is to allow consistent, reliable deposition of the paste by dispensing and, occasionally, by other means.

Virtually all solder paste used in the industry is of the RMA type; the reflowed assembly is cleaned in an organic solvent. Occasionally, water or water and a saponifier can be used. It is possible to apply a No-Clean paste successfully to a die attach project, omitting the cleaning step, but encapsulation must proceed successfully without delamination troubles, and the device must function properly with no shorts. “No Clean” qualification involves testing at 100 V. Many packages are designed for 1,000 V or more.
Solder wire can be produced by extrusion or drawing. One type can be produced by drawing and is sold by length in nominal diameters. This type may have a ribbon shape, but is still referred to as wire. During the die attach process, the wire contacts the preheated lead frame to produce a deposit of molten solder.

A closely related process requires a more precise nature of wire. The wire enters a volumetric chamber grounded on the lead frame, where it is melted to fill the chamber with an exact amount of molten solder. Since the wire acts not only as the source of molten solder, but also as a piston to displace the melt from the entry port, it must be of a precise, consistent diameter (for example, 30 mil ± 0.8 mil or 0.762 mm ± 0.02 mm). Impurities in terms of light, salt-forming elements and oxygen must be low to avoid the formation of slag-like deposits that adhere to the chamber. Wire is often doped with ppm levels of additives (Ge, Sb) to improve wetting. Once the exact deposit of molten solder is generated, the process proceeds. Wire is available from 10- to 50-mil in diameter, but the vast majority used is 30 mil.

**Deposition**

Dispensing robots are sometimes purchased as stand-alone units, but most often die attach operations are conducted on assemblies of modules that deposit solder or adhesive, place the chip or chips and any clips in a series of steps, and reflow the solder or cure the adhesive.

Whatever type is used, the solder or adhesive normally is deposited by one of three methods: an adjustable screw feed, an adjustable time-pressure device or pressure feeding a volumetric device. The volumetric type reputedly gives the most accurate, consistent deposit. The time-pressure method has surpassed the volumetric scheme, but care must be taken to limit the pressure when using solder paste or compaction and resultant clogging will take place. Using a longer time and lower pressure is advisable. The screw feed method appears to be the wave of the future. Care must be taken with solder particle size, or jamming of the screw feed and intermittent operation may result.

Processes can be devised where solder is printed on a lead frame using a stencil, as in the SMT process. Since the pattern is simple compared to an SMT board, with no fine-pitch deposits necessary, the printing characteristics of the paste need not be rigorously controlled.

Pin transfer is a simple, but effective, method to deposit solder paste or flux. Basically a multipin instrument or bed of nails, it dips into a flat, open container of solder paste or flux. The pins are grounded on the lead frame and the paste is deposited. However, unavoidable variations in the rheology of the paste require frequent adjustments of the pin depth travel or dilution of the particular batch of paste to achieve the correct deposit size.

**Reflow**

Most packages are mechanically stressed by extreme variations of temperature during operation, especially power devices. To properly dissipate thermal energy in such instances, a highly conductive metallic solder joint is required between lead frame and die. This connection must have sufficient thermal conductivity and mechanical strength to withstand the considerable stresses generated. For this reason, voiding, the presence of gaseous or liquid pockets in the body of the solder filet, is unacceptable. The integrity of the solder attachment is decided by how it is constructed, and thermal history or reflow profile is decisive.

The solder or solder paste deposit must be subjected to a heating regimen in a suitable atmosphere that allows a sequence of events to take place and produce a proper void-free or nearly void-free bond between the chip and the lead frame. The application of heat must raise the temperature of the components until volatiles evaporate and the alloy or alloy powder melts to a free flowing, nonviscous liquid, along with any nonvolatile vehicle components. The two liquids, molten metal and the organic vehicle phase, must have time to coalesce and separate so that the molten metal forms a bond to the chip and lead frame surfaces without inclusion of any gases or organic liquids.

Too long or hot a profile can result in a too-thick intermetallic layer, regenerating voids and, in the case of paste, possibly scorching and polymerizing the organic vehicle residue. A thick, brittle, intermetallic layer greatly shortens the life of a package because of the development of fractures along the bond line. This is a problem with higher tin solder alloys used on copper. Even a proper joint of this type will deteriorate over time when subjected to high temperature, caused by the Kirkendall effect. In such cases, the intermetallic layer grows in thickness through diffusion in the solid state. The layer becomes so thick and brittle that the joint fails by a fracture mechanism.

**Atmospheres**

A reducing atmosphere is required because of the high reflow temperatures of common die attach alloys. Forming gas, 5 percent hydrogen in nitrogen, is normally used. At 300°C and above, certain components in solder paste vehicles or added preform fluxes will act as oxidizing agents on metal surfaces. This is prevented or reversed by the hydrogen component. The hydrogen also will remove the remnants of oxide present on the solder wire.

**Conclusion**

Although lead frame packages are the most common and inexpensive, the die attach process has considerable technical content. This area is poised for substantial growth in the years ahead and the appearance of innovative new products.

**References**

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